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REPORT ON A MEETING

FOR CONSULTATIONS ON UNDERWATER NOISE

Rome, Italy, 17-19 December 1968

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
ROME, 1970

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PREPARATION OF THIS REPORT

This report was prepared jointly by the experts participating in the meeting for consultations on underwater noise held in Rome, 17-19 December 1968.

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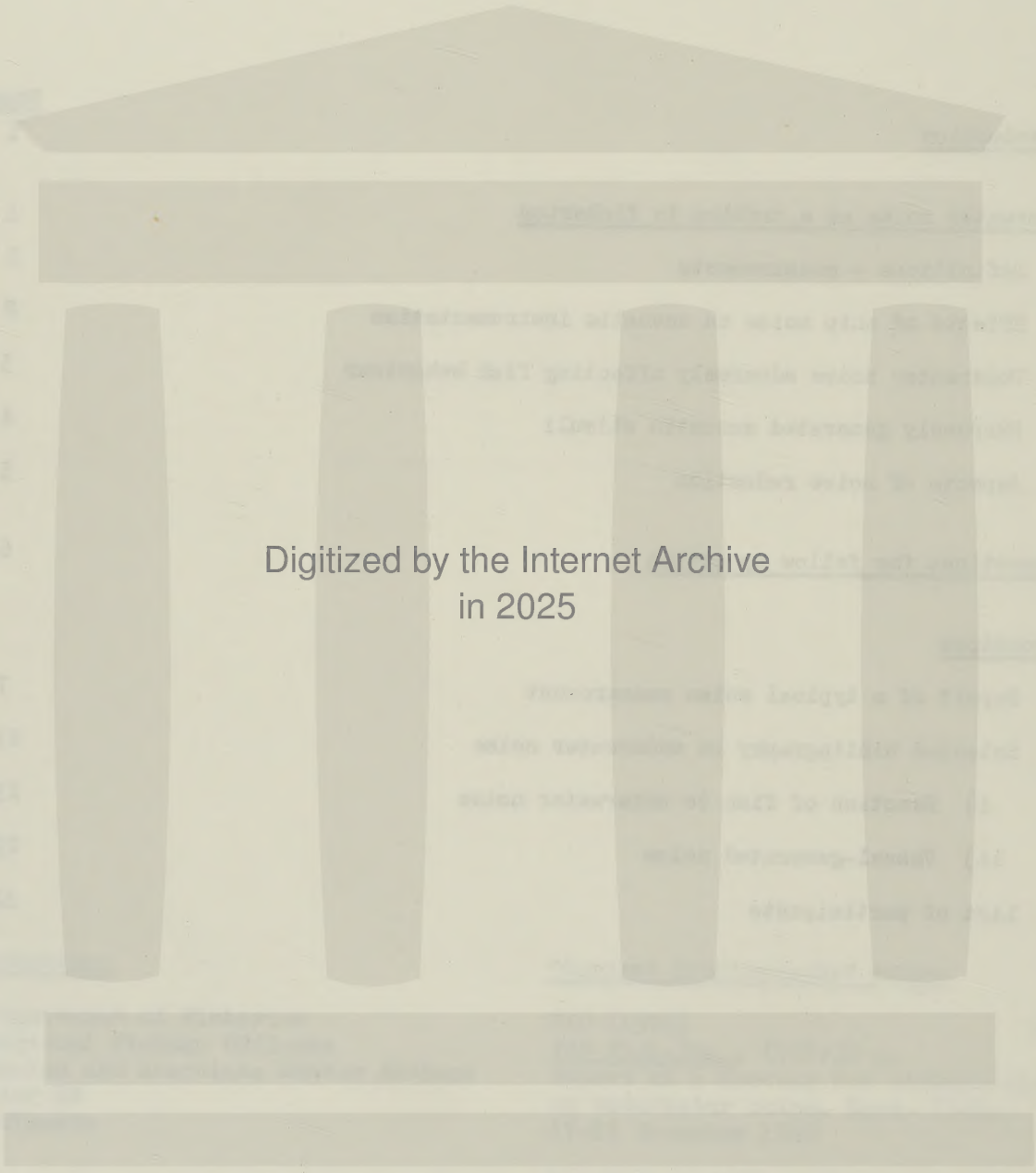
CONTENTS

		Pages
I	Introduction	1
II	Underwater noise as a problem to fisheries	1
	1. Definitions - measurements	1
	2. Effects of ship noise on acoustic instrumentation	2
	3. Underwater noise adversely affecting fish behaviour	3
	4. Purposely generated acoustic stimuli	4
	5. Aspects of noise reduction	5
III	Suggestions for follow up action	6
IV	Appendices	
	A Report of a typical noise measurement	7
	B Selected bibliography on underwater noise	23
	i) Reaction of fish to underwater noise	23
	ii) Vessel-generated noise	29
	C List of participants	31



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I. INTRODUCTION

When originally fishing vessels became mechanized, fishermen feared that the noise created by the engine and propeller would scare the fish away. This is still a problem for FAO when mechanizing fishing vessels in developing countries. However, after mechanization, it is mostly found that fish catches increase and noise seems to be of little importance.

Lately, however, with the increased use of purse seining and other types of fishing for pelagic fish, such as pole and line fishing for tuna, it has been found that there are differences between similar vessels in the ability to catch fish, which cannot be explained by differences in the degree of skill of the skippers or fishing luck.

In some cases a rattling rudder has been found to frighten fish away, in others an excessively vibrating auxiliary engine had the same effect. By measuring underwater noise, large differences in sound pressure level have been found between ships of the same type. Thus, manufacturers of sonars report cases of differences between the same type of craft being so great that the efficient range of the same sonar equipment can vary from 1,200 m to 2,800 m.

For the purpose of discussing the influence of underwater vessel noise on the range of acoustic instruments and on fishing, the Department of Fisheries convened a consultative group in Rome from 17 to 19 December 1968 under the Chairmanship of Jan-Olof Traung, Assistant to the Director, Fishery Resources and Exploitation Division. The following report of these discussions is, to a great extent, the joint work of the consultants whose interest and willingness to share their experience with the Department of Fisheries are gratefully acknowledged.

II. UNDERWATER NOISE AS A PROBLEM TO FISHERIES

1. Definitions - measurements

Noise levels are almost exclusively given in terms of dB referred to some standard intensity or sound pressure. For intensity measurement one has:

$$I\ (dB) = 10 \lg \frac{I}{I_o},$$

where I is the measured intensity, and I_o a reference value. For sound pressure measurements:

$$p\ (dB) = 20 \lg \frac{p}{p_o},$$

where p is the measured pressure, and p_o is a reference value, usually 1 bar. The reference value should always be stated to avoid misunderstanding.

The usual way of presenting noise levels is by the so-called index value of spectrum level. This is a theoretical, but highly convenient term, which gives the noise level within a 1 Hz band at a point 1 m from the apparent centre of the noise source.

Dealing with noise - or sound fields, one divides the environment in a near-field and a far-field. The near-field is within 1 wavelength from the centre of the source. (For seawater this will represent a distance of 15 m at 100 Hz).

Except for extremely low frequencies the noise observed by the fish is nearly always far-field noise. The noise thus observed is referred to as wideband - far-field noise, or just wideband noise. Wideband noise is usually analysed within a frequency-range from 25 Hz and up to 15000 Hz. This noise is a function of many parameters, such as vessel speed, propeller - and engine revolution, pitch setting and so on.

The sonar self-noise is the noise picked up by the sonar transducer itself, when the sonar is operated as a listening device. This noise is measured at the sonar-frequency, and over a bandwidth in the order of 200 Hz. It is highly dependent upon the vessel speed, but also on the parameters mentioned for the wideband - far-field noise. This also applies to vertical echosounders.

The sonar self-noise is measured by attaching a suitable instrument to the output terminals of the sonar receiver. By knowing the transducer sensitivity and total amplification through the system, the measured noise-voltage can be readily transformed to actual noise level at the transducer head.

The wideband - far-field noise is measured by mounting a hydrophone in the water, and having the ship pass at a suitable distance. The noise picked up by the hydrophone is usually recorded on tape for later analysis. By knowing the distance and the sensitivity of the system, the recordings can be converted into actual noise levels.

Sonar self-noise is usually presented as noise versus speed for different pitch-settings. Another way is to plot noise against transducer listening direction for different speeds.

The wideband - far-field noise is usually presented as index value of spectrum level, that is, noise against frequency for different pitch-settings and rpm Another way is to plot noise at different frequencies versus speed for different pitch-settings.

2. Effects of ship noise on acoustic instrumentation

Noise is one of the major limiting factors in the use of sonar and echosounders. A high noise level reduces the detection capabilities of a system, and a low signal to noise ratio reduces the possibilities of echo classification and makes quantitative measurements of the echoes received of doubtful value.

The sonar self-noise which is picked up by the transducer is dependent on a number of factors, of which the most important ones are:

Type of vessel
Vessel speed
Type of engine and propeller
Number of revolutions and pitch settings
Location of transducer
Weather conditions
Water depth

Self-noise, both in sonar and echo-sounder installations has been measured on a great number of vessels, and very great variations in noise level from one ship to another have been observed. An example of this, which also illustrates how sonar self-noise increases drastically as a function of vessel speed, is given in Fig. 1:

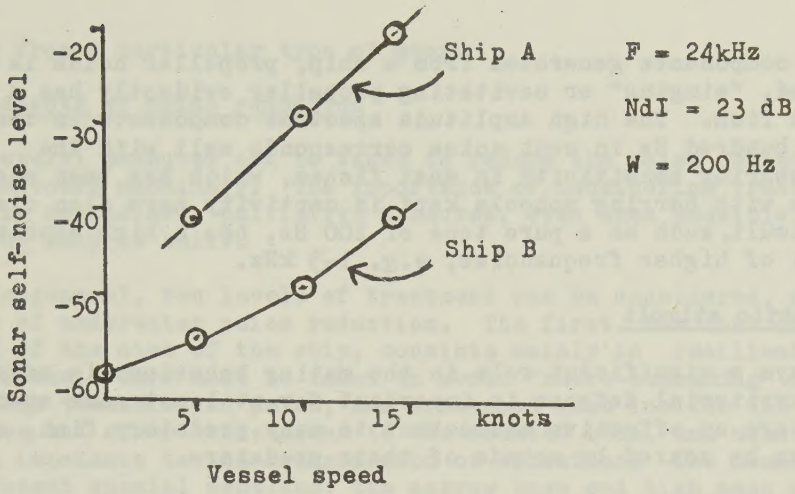


Fig. 1 Sonar self-noise plotted against vessel speed for two different installations.

The measurements refer to two similar 24 KHz sonar installations on board two purse seiners of the same size (approx. 110' in length), but quite different in construction and with different engines and propellers. A difference in noise level of approximately 20 dB was observed at a speed of 10 knots. This corresponds to a difference in maximum detection range of some 40%.

3. Underwater noise adversely affecting fish behaviour

The main evidence of adverse effects on fish behaviour is based on observations made in the purse seine fisheries for clupeoids, mackerel, tuna, saithe, etc. A few reports of noise effects have also been given from trawl fisheries, especially from midwater trawling for herring.

In several purse seine fisheries for surface schooling fish, there is clear evidence of the schools being scared by noise generated by the fishing vessels. Especially sudden changes in noise level in vicinity of a school (e.g. caused by changes in rpm, pitch setting, etc.) very often cause immediate fright reactions, typically by diving but avoidance by orientated change in swimming direction does also frequently occur. Sometimes an adaption to a high but constant noise level is observed and this may even inhibit the normal behaviour towards a certain stimulus, or generally raise the reaction threshold.

The pronounced effect on fish behaviour by noise stimuli is also a question of the biological and environmental situation. Typically the Atlanto-Scandian herring schools are more easily scared during certain periods of the year, such as when feeding during summer and in the early migration stage in the late autumn. During the feeding period of the saithe the kind of food eaten has shown to be most important for how scary the schools are.

Observations in nature show varying degrees of scaring when different kinds of sound and noise stimuli are applied. Thus, schools of herring have been observed to behave quite indifferently towards a full speed running trawler while towards a towing trawler they seemed to start a violent escape behaviour.

Only very little is known about precisely which characteristics in ship noise can cause fright reactions, but it seems likely that low frequency noise is most

important. Among the noise components generated from a ship, propeller noise is very significant and an unbalanced, "singing" or cavitating propeller evidently has a pronounced scaring effect on fish. The high amplitude spectral components in the frequency range below a few hundred Hz in such noise corresponds well with the frequency range of optimum hearing sensitivity in most fishes, which has been shown to be below 1 KHz. Experiments with herring schools kept in captivity have also clearly shown that low frequency stimuli, such as a pure tone of 100 Hz, has a high scaring effect compared with stimuli of higher frequencies, e.g. 1-5 kHz.

4. Purposely generated acoustic stimuli

Acoustic attraction plays a significant role in the mating behaviour in many fish and acoustic repelling in territorial defense is important for at least some species. Sounds associated with prey are an effective attractant to many predatory fish, on the other hand many clupeoids can be scared by sounds of their predators.

Laboratory experiments have repeatedly demonstrated that fish are easily conditioned to approach a sound source, and artificially generated feeding sounds have thus been used to concentrate pond reared fish for harvesting. Migrating salmonids have been influenced by low frequency sounds (35-170 Hz) into collection facilities for passage around hazardous areas, and underwater acoustic equipment has been used successfully to lure carps and yellowtail.

In many commercial fisheries acoustic techniques for influencing fish behaviour are also used although the specific behavioural context is often not quite clear. Examples from different parts of the world are: Fish shoals being driven into a net from sound produced when beating the sea surface by a bamboo pole, or by stones thrown into the water. Water-spray noise in skipjack fishery resembling the noise of live bait and reducing the range of the optical sense. Gathering of carp and similar fish by tapping the side of a boat with a stick, and gathering of porgy (sea bream) with sound produced by throwing small bell-shaped objects ("boko") into the water.

The most important characteristic or parameters of sound for influencing fish behaviour are frequency, duration and intensity. The region of low frequencies from 1 kHz down to infrasound (vibration) should be most effective, and pulsed sounds of more than 1-3 msec are much more effective than continuous sound. Fish will usually not react towards broad-band high energy noise from sparkers of 1-2 msec duration, but spots of 100 msec up to several seconds can be effective. Thus, pulses of 1 KHz and 10-15 seconds duration have been used successfully to drive schools of herring and cod down to the seabed.

The optimum signal characteristics for influencing fish behaviour cannot, however, be specified in general for all fish of commercial interest because the behavioural effect of a given noise type will vary with respect to the "biological receiver" concerned. For instance, there are differences between predator, and prey fish and the response of each species will vary to a high degree with seasonal and physiological factors.

Two other aspects should be underlined:

1) Biological sounds normally produced as a by-product of certain activities like swimming, feeding, etc., as well as technical noise can gain in significance by means of established individual experience.

2) The escape reaction from trawls, purse seines, and other active gear can be reduced by creating "secondary stimuli". If the fish's sensors are taxed by other or secondary stimuli, these may confuse and even inhibit the behaviour that might lead to

escape from a particular type of gear.

5. Aspects of noise reduction

Several measures can be taken to reduce the noise radiated into the sea originating from on-board machinery. The importance of considering treatment early in the design stage is emphasised; palliative measures, even when possible, can be very expensive once the ship is built.

In general, two levels of treatment can be considered, depending on the required degree of underwater noise reduction. The first, the cost of which is probably about 2 - 3% of the cost of the ship, consists mainly in resilient mounting of high noise level items. Care must be taken to avoid "short-circuiting" of the mountings by other vibration transmission paths, and treatment must include the provision of flexibility in pipes and other connections to the mounted item, and mounting seatings which present a high impedance to the transmission of vibration. The mounting of main diesel engines can present special problems: the narrow base and high mass centre of most diesels result in a large overturning moment in a seaway and hence large motion if the engine is soft mounted; internal out-of-balance moments and forces can result in large amplitude vibrations; main shaft and other connections to the mounted item must be capable of accommodating these movements, and it is usually necessary to include main shaft flexible couplings in the installation. The value of attenuation by such treatment will be 10 - 15 dB and with noisy engines, such as diesels, the attenuation will be limited by airborne noise transmission exciting the hull, particularly in reverberant spaces below engines and gearboxes.

The second level of treatment, which aims at a much greater reduction in underwater noise, is probably applicable mainly to research vessels, and may cost about 8% of the total cost of the vessel. The ERNEST HOLT replacement vessel of the U.K. Ministry of Agriculture, Fisheries and Food is cited as an example. In this ship, which is at present under construction, the drive is diesel electric. The two main diesel generators, the auxiliary diesel generator and the noisy rotating auxiliaries are mounted on a heavy raft (about 10 x 15 m) of box frame construction, the girders being roughly 60 cm. deep. The whole rectangular frame is covered on the top with a $2\frac{1}{2}$ cm. thick plate, and the raft mounted machinery is enclosed in an acoustic enclosure. which sits on top of the skirt. The raft is supported on an "active" air mount system (developed by Y-ARD), which maintains the position of the raft relative to the seating within about $\frac{1}{2}$mm under rolling and pitching conditions. This enables stops to be fitted with a nominal clearance of about $1\frac{1}{2}$ mm., so that if for any reason the mounting system is inoperative, the raft "sits down" on these solid stops. The mounted weight is about 270 tons, the mean air-pressure in the mounts about 20 atmospheres, maximum pressure about 30 atmospheres, and the maximum air flow through the system under rolling conditions about 5 standard cubic metres/min, supplied from a boost compressor operating in a closed circuit. In order to reduce the airborne noise level outside the enclosure to the target of about NR 60, special panels were developed for the enclosure, and attention had to be paid to acoustic treatment of the enclosure air supply and ventilation systems, the diesel exhausts and all service attachments to the raft. Access into the enclosure is by sealed door and a number of viewing windows are provided.

Other noise treatment on the ship includes the addition of concrete infill between frames, bonded to the frames and hull, in the region of the propulsion electric motor and thrust block. The propeller is a kort nozzle with special damping treatment of the shroud. The hull plating below the waterline is thicker than usual to avoid irregularities in the surface. The underwater noise target level for this ship is about 3 dB above the ambient level associated with sea state 3 at 100 m from the ship.

One of the most important sources of underwater ship noise is the propeller, and especially in the purse seine fisheries propeller noise is significant. About 1964-1965 it was realized that insufficient attention had been paid in Icelandic purse-seiners to the accuracy of propeller manufacture, particularly as regards balance and uniformity of blade profile between blades. On propellers of total weight approx. 100 kg., a 3 kg., difference in blade weights was sometimes observed where the specification called for a maximum variation of 0.2 to 0.3 kg. Change of propeller blades had in such cases often reduced the noise pattern very much. The method of using the vessel, i.e. pitch setting and rpm, etc., is also found to be of great importance when approaching a school of fish.

U.S. investigations on the noise field around a ship show that the noise transmitted from the propeller is mainly propagated (at high frequencies) on either side of the ship with relatively low transmission fore and aft. Recent work in Norway used a plot of delivered hp versus propeller rpm for various pitch settings. A grid of noise output curves was superimposed, so it became possible to choose the optimum pitch for minimum radiated noise at any given rpm. It was found that radiated noise varies as $p = \text{const.} \times N^{\alpha}$ where p is sound pressure, N is propeller rpm, and α is a varying exponent. Between half and full propeller speeds a value of $\alpha = 3.7$ has been found to give a reasonably good result.

Hydrodynamic ship noise is also reported to be a significant factor which should be seriously considered already at the design stage. Thus, a bulbous bow may produce a high noise level under pitching conditions, and the detailed shape and finish of keel and rudder is known to affect the noise level markedly. In some Icelandic purse-seiners changes made to the keel construction (strips welded to the bottom of the bar keel and up to the keel strake, forming a V with the bottom of the keel at the apex, extending from the stem to just abaft the position of the sonar, gradually tapered off at this point), resulted in a noise reduction of 4-5 dB at 24 kHz.

III. SUGGESTIONS FOR FOLLOW UP ACTION

1. It was agreed that a compilation of a comprehensive bibliography would be very useful, and all participants undertook to submit references on this subject on their return. These references are now given in Appendix B.

2. FAO should sponsor the reproduction of some suitable standard text on underwater noise as a problem to fisheries which could then be used as a general introduction into the subject. It was suggested that Mr. Truls Gjestland's thesis (in Norwegian) entitled: "Generation of Underwater Noise by Vessels, its Character and its Influence on Fishing and the Use of Sonar Equipment", could be updated and translated into English, and it was generally agreed that it would be of great advantage if FAO could have this reproduced.

3. It was also agreed that the report of the consultations should be distributed to organizations working on problems in this field and their future collaboration invited. Similarly, it was considered of particular value to send the report to manufacturers of propellers and acoustic instruments.

4. It was agreed that ACMRR should be informed of the outcome of the consultations and that their suggestions for future action by FAO in this field should be invited.

APPENDIX A

CALIBRATION OF
EK38A, EK120A AND SK3
ON THE
COLOMBIAN RESEARCH VESSEL
R/V "CHOCO"

(Owned by UNDP/SF/FAO)

May 1969
SIMONSEN & MUSTAD A.S, Horten
Norway

WIDE BAND NOISE MEASUREMENT ON THE PERUVIAN RESEARCH VESSEL SNP 1

1. MEASUREMENT PROCEDURE

The measurements were carried out at the SIMRAD test range off Hurumlandet in Oslofjorden Tuesday November 12, 1968, when the vessel was in Horten for the final check-up and calibration of her accoustical instrumentation.

The depth was approximately 50 fathoms. Relative windspeed was 1 and seastate ½.

The recording equipment was arranged according to fig. 1 onboard R/V SIMRAD. This boat was lying at anchor with all her machinery turned off (silent ship). The necessary electricity was delivered by accumulators via a static inverter.

The hydrophone was suspended over the side of the R/V SIMRAD at a depth of 15 meters.

R/V SNP 1 made several runs at different rpm- and pitch-settings. The noise was recorded when the boat passed the hydrophone at a distance varying from 50 to 100 meters. This distance was checked by means of radar.

Recordings were also made without the propeller running, and when the sidepropeller was operating.

Fig. 3 shows the general arrangement of the measuring-set-up.

2. RESULTS

The result of the frequency analyses is plottet on diagram 1 to 9. The recording and analysing instrumentation is given on fig. 2.

All noise levels are given in dB re 1 μBar with a signal bandwidth of 1 Hz and referred to a point 1 meter from the centre of the source.

The recordings were analysed in 1/3 octave band, and then reduced by 10 lg ΔF, ΔF being the bandwidth in Hz.

The calibration was done by means of a known reference signal and the given voltage sensitivity of the transducer.

3. DISCUSSIONS

The noise-spectrum levels show no special irregularities. Engine-noise is the dominating factor at low frequencies, while the propeller noise is noticable in the region between 200 and 2000 Hz.

At low propellerspeed the pitchsetting seems to be unimportant, but at higher speed the noise will decrease with increasing pitch, (and decreasing propeller speed).

Thus the general rule will be always to use the highest possible pitch, and reduce the engine rpm accordingly, to operate at any given speed.

Compared with other similar boats, SNP 1 has an average, or a little below-average, noise-spectrum level.

A peculiar resonance phenomenon is observed at 50 times the main engine's fundamental frequency. The resonance is rather small, but it can clearly be seen from the noise-spectrum of the main engine alone.

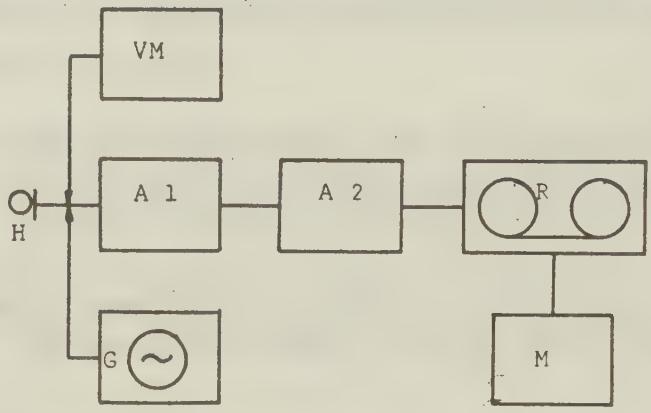
The main engine working at 1200 rpm should thus give a resonance frequency

$$\left(\frac{1200}{60}\right) \cdot 50 = 1000 \text{ Hz}$$

The same thing is observed at all speeds. The actual reason for this is not quite clear, but should possibly be investigated further.

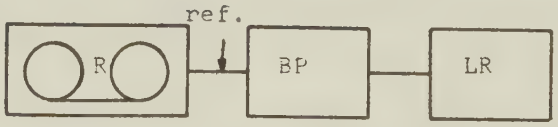
The noise level from the sidepropeller is high, but not as high as to indicate a possible metal-to-metal contact as pointed out by the FAO representative onboard.

Measurements of the rudder-control showed no increase in the noise level when the rudder was operated.



H : Hydrophone, LC 32
VM: Voltmeter, Hewlett & Packard
A1: Amplifier, Hewlett & Packard, 465A
G : Sine generator, Hewlett & Packard
A2: Amplifier, Brüel & Kjær, 2409
R : Tape recorder, Nagra III
M : Monitor

Fig. 1. Schematic diagram. Recording



R : Tape recorder, Nagra III
ref: reference signal
BP : 1/3 octave bandpass filter, Brüel & Kjær 1612
LR : Level recorder, Brüel & Kjær, 2305

Fig. 2. Schematic diagram. Analysing

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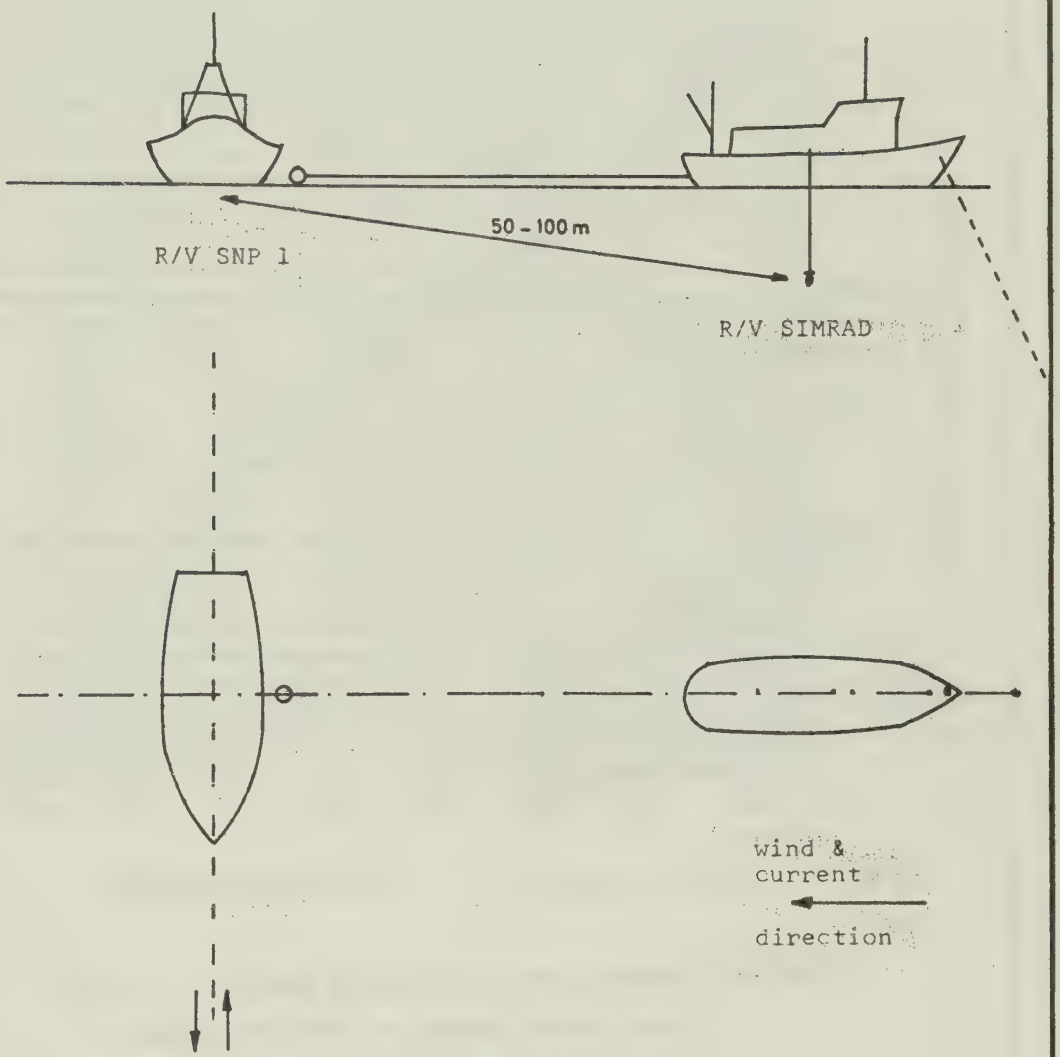

Fig.3. General arrangement of the measurements

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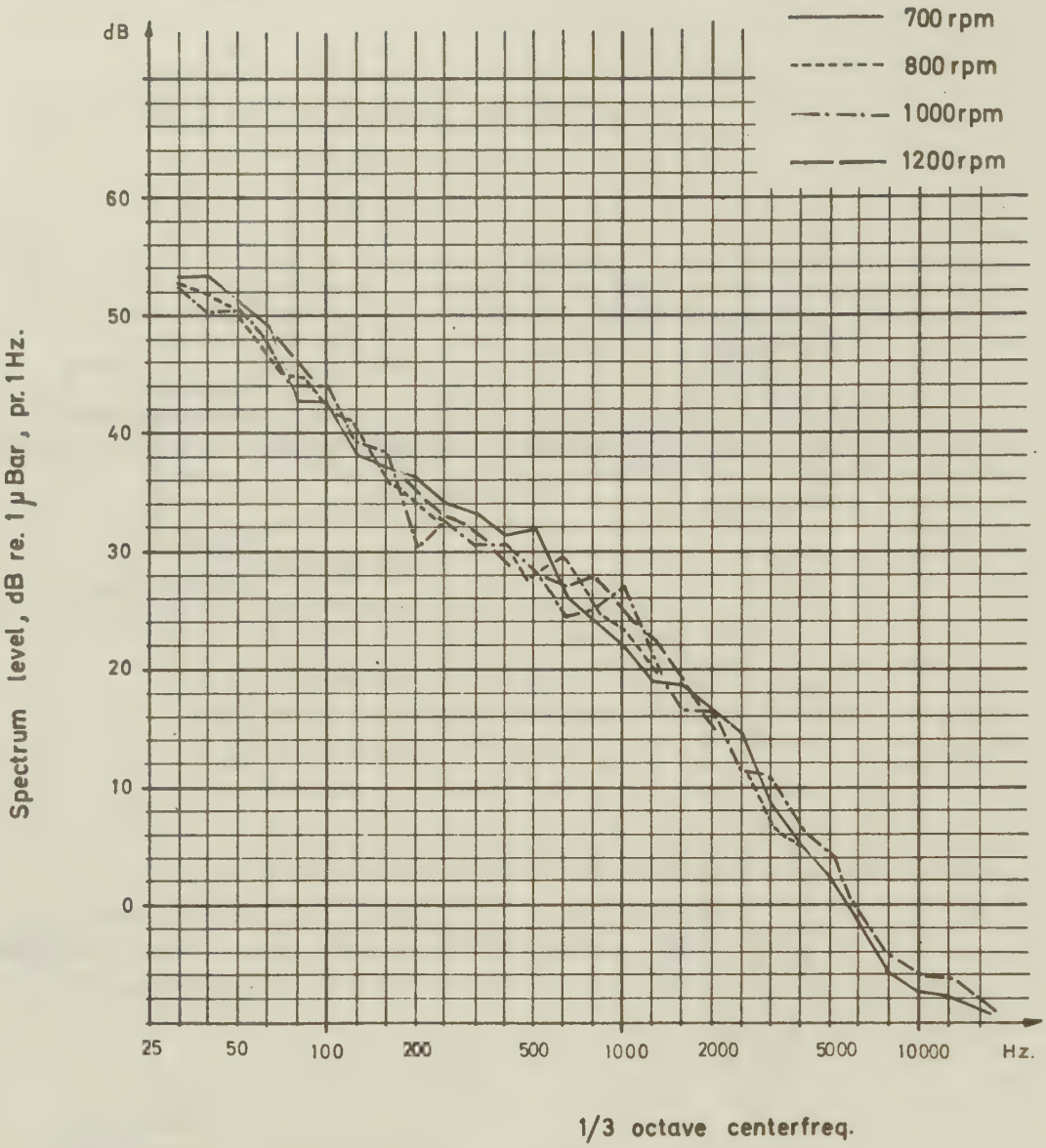

Diagram 1. Observed noise from R/V SNP 1.
Main engine running at different speeds,
without propeller working.

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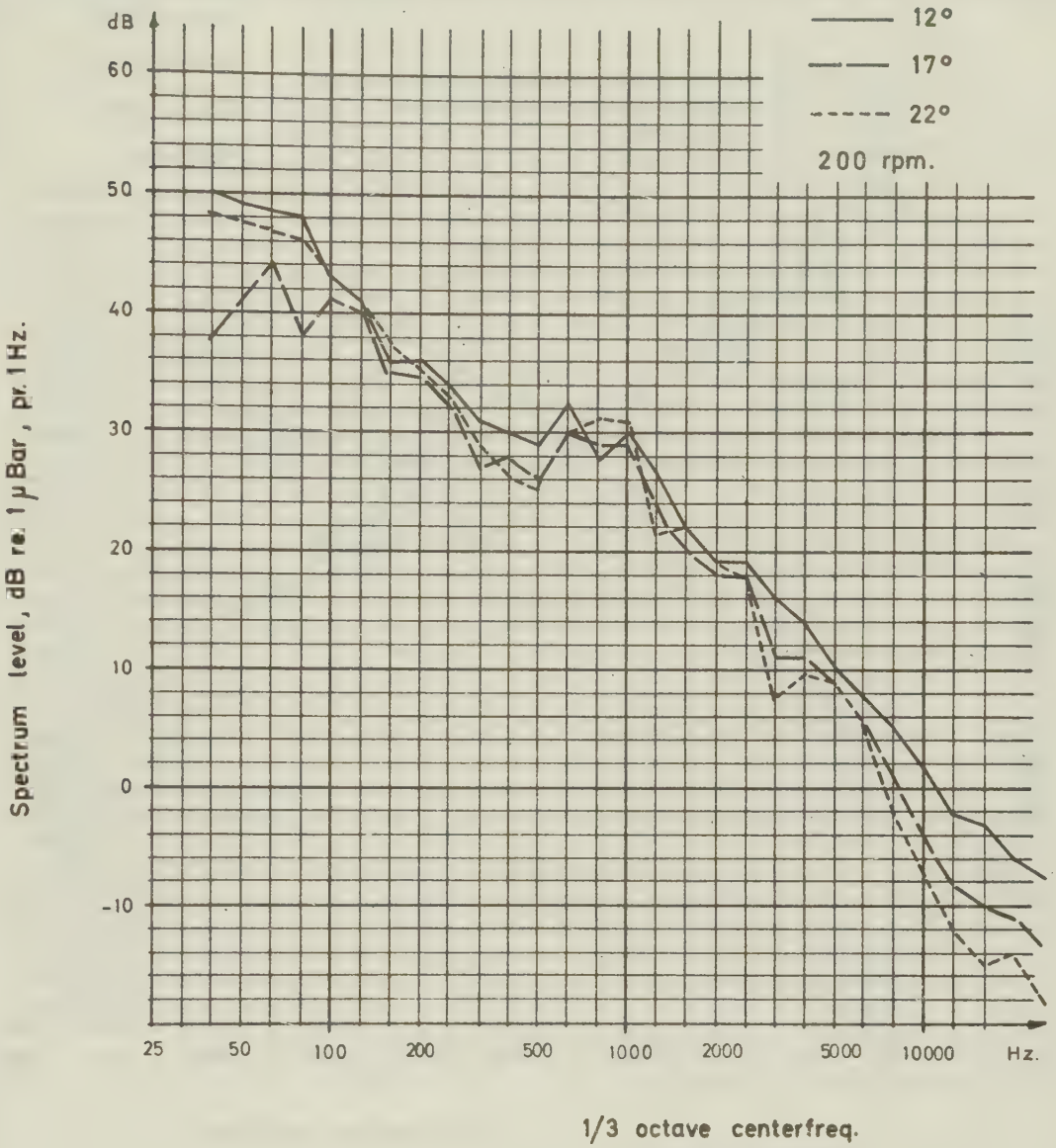

Diagram 2. Observed noise from R/V SNP 1.

Main engine : 700 rpm.

Propeller : 200 rpm.

Pitch : 12, 17, 22 °

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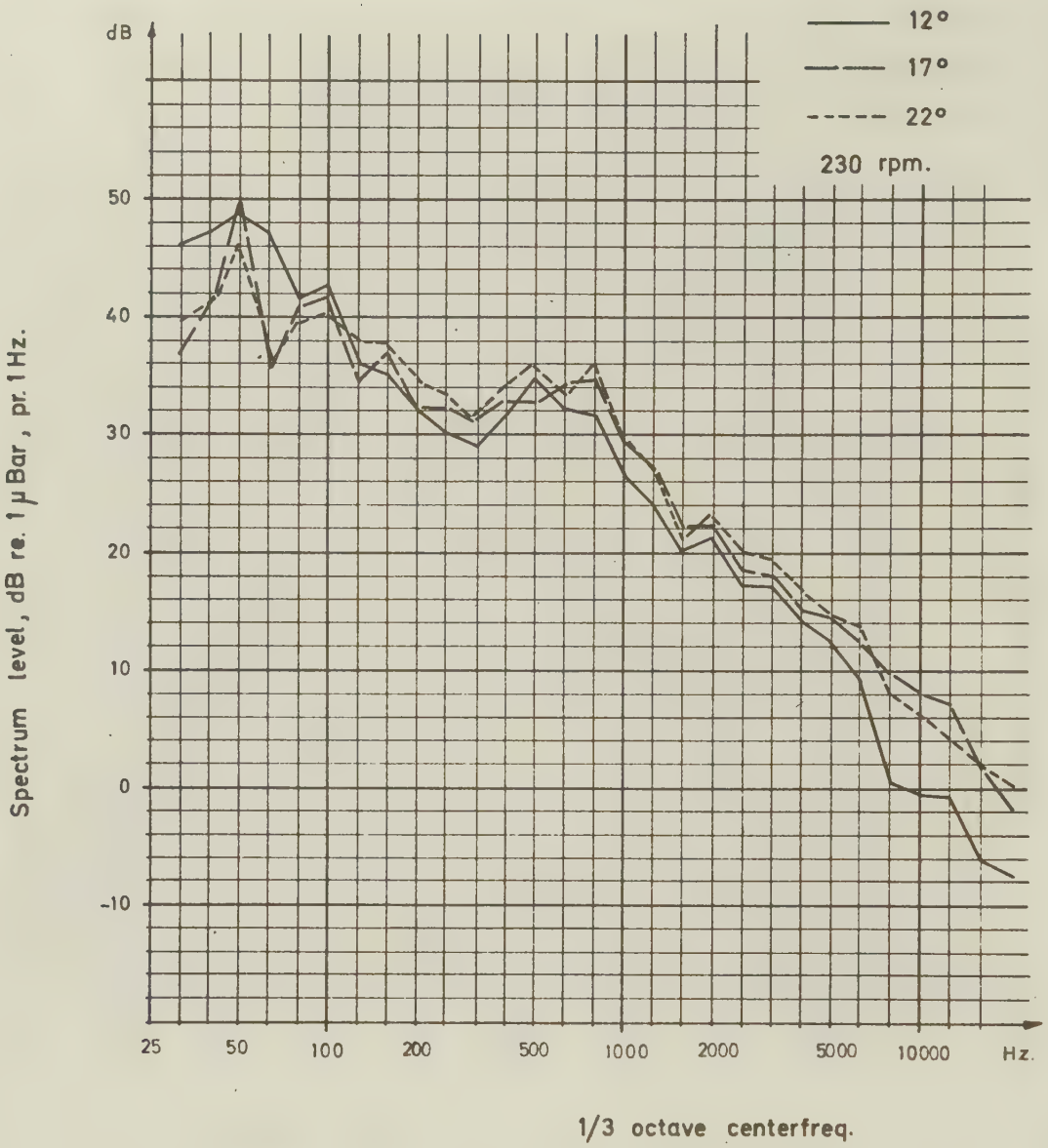

Diagram 3. Observed noise from R/V SNP 1.

Main engine : 800 rpm.

Propeller : 230 rpm.

Pitch : 12, 17, 22 °

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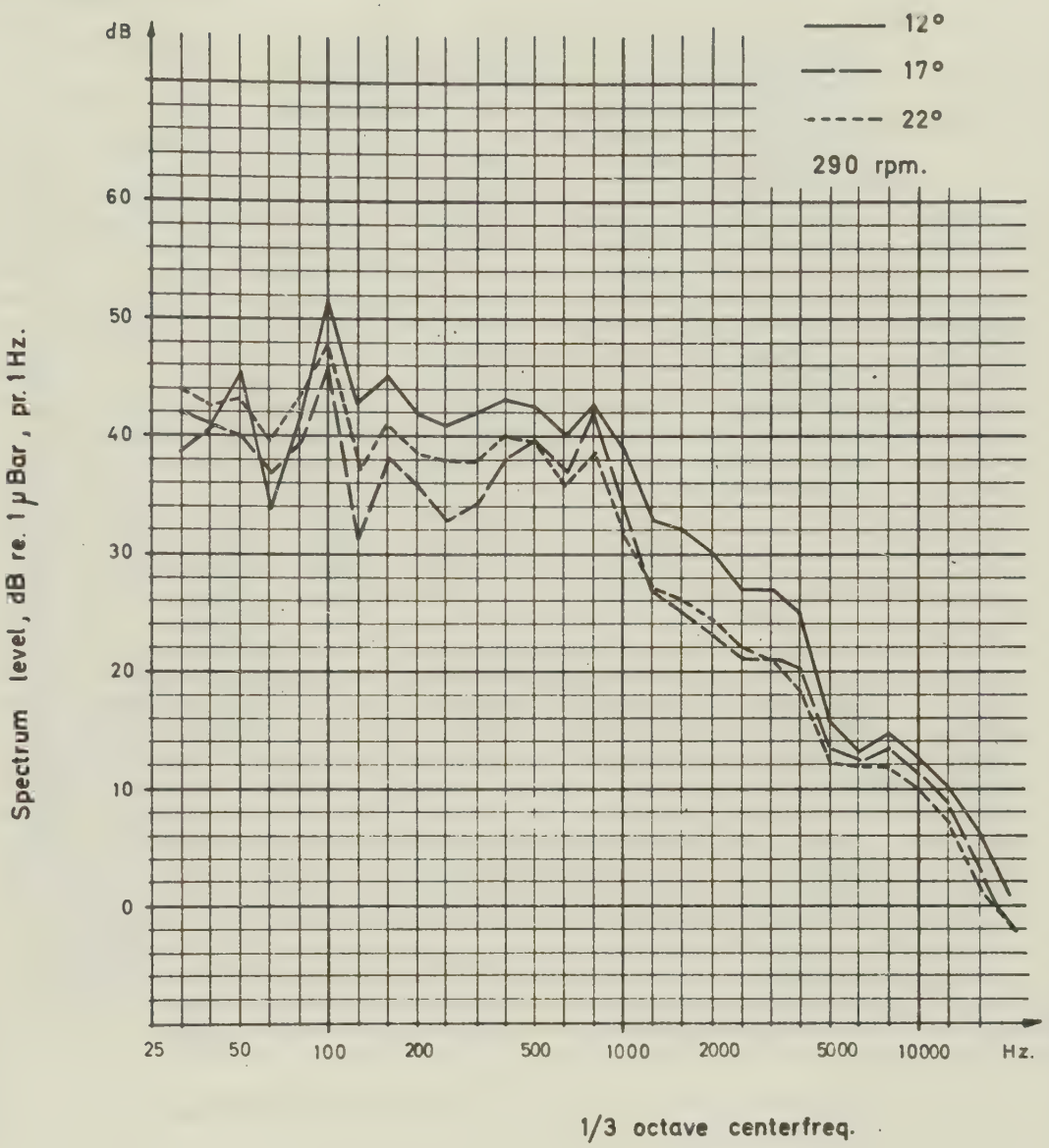

Diagram 4. Observed noise from R/V SNP 1.

Main engine : 1000 rpm.

Propeller : 290 rpm.

Pitch : 12, 17, 22 °

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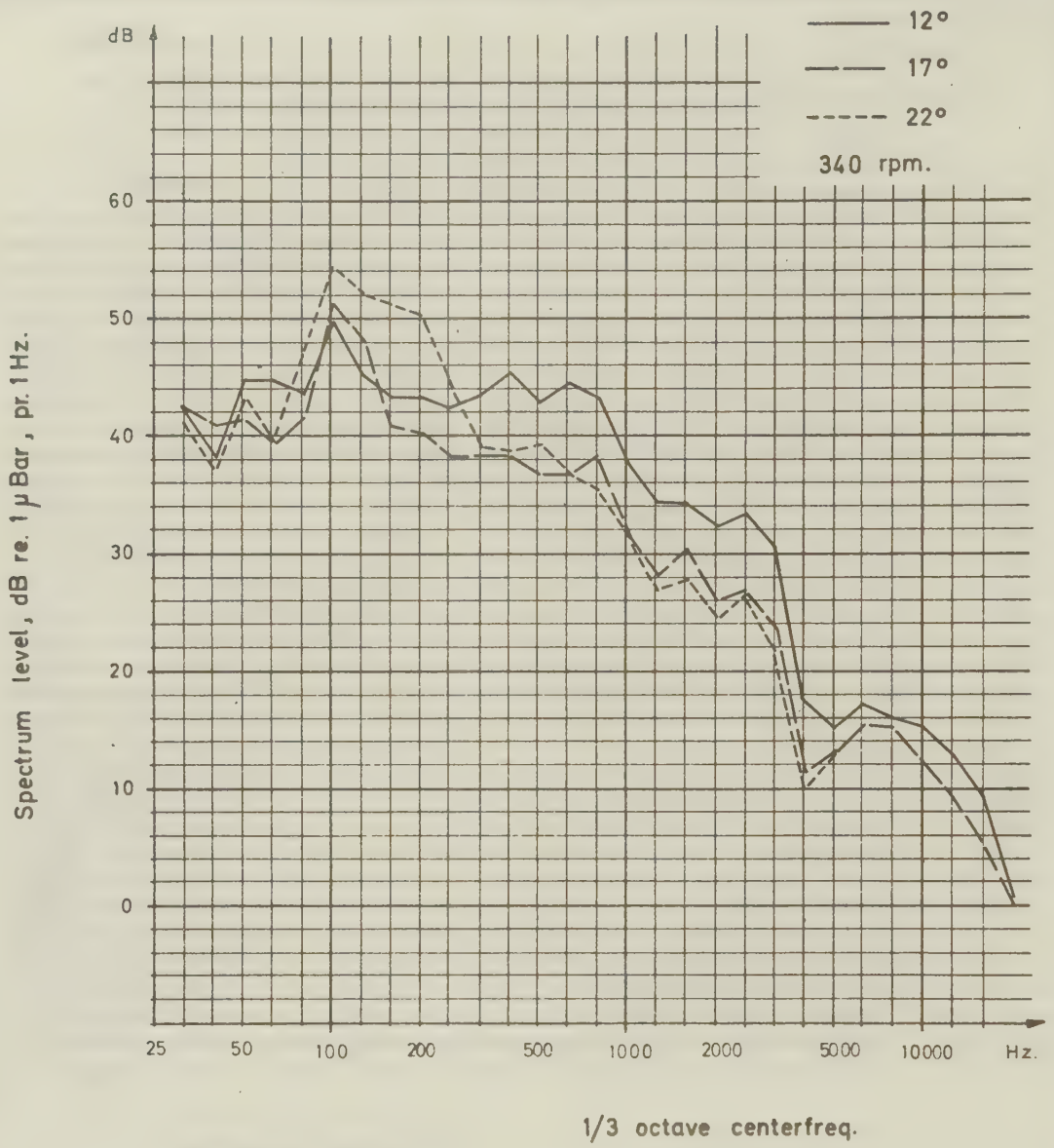

Diagram 5. Observed noise from R/V SNP 1.

Main engine : 1200 rpm.

Propeller : 340 rpm.

Pitch : 12, 17, 22 °

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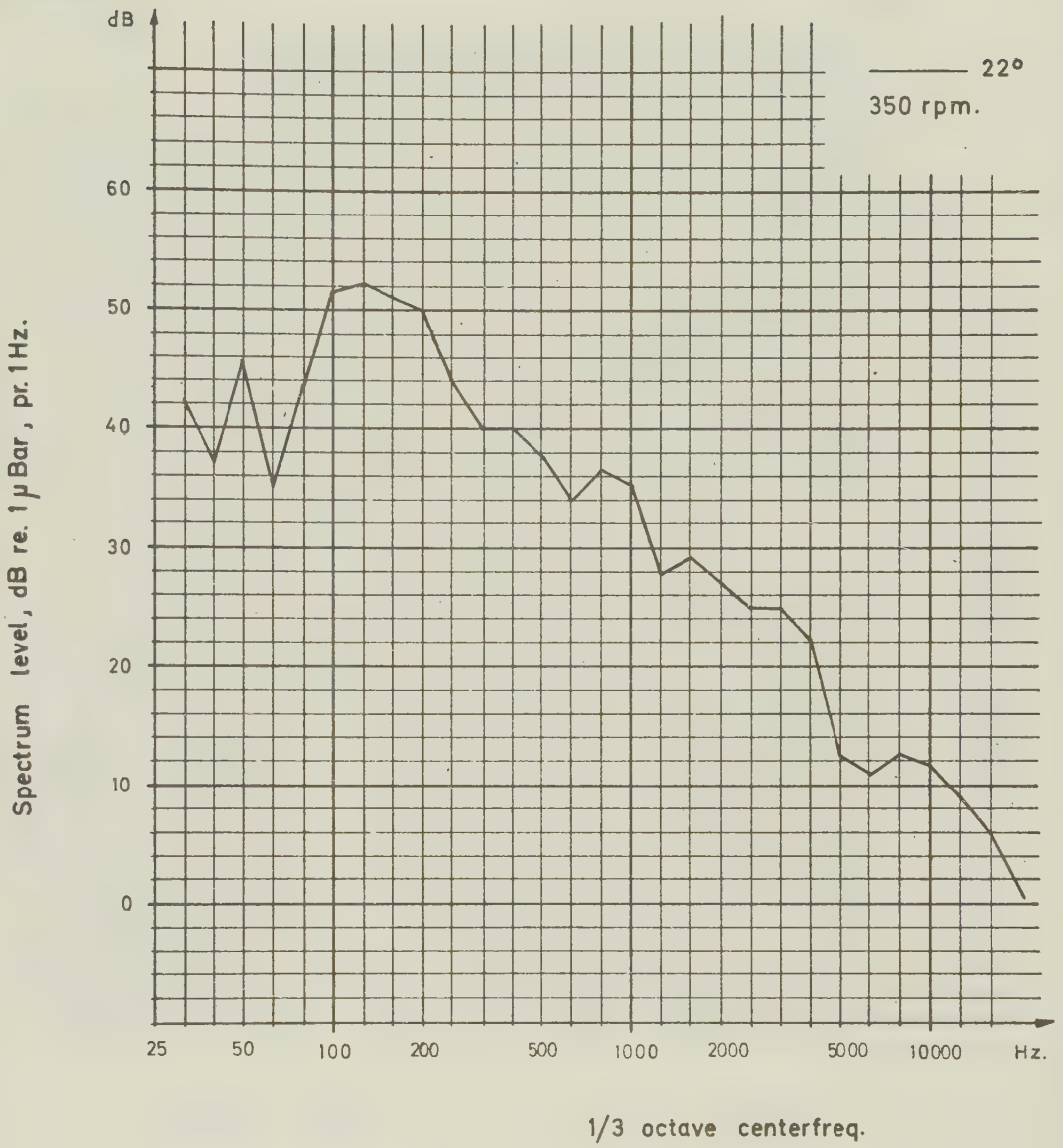

Diagram 6. Observed noise from R/V SNP 1.

Main engine : 1225 rpm. (max)

Propeller : 350 rpm.

Pitch : 22°

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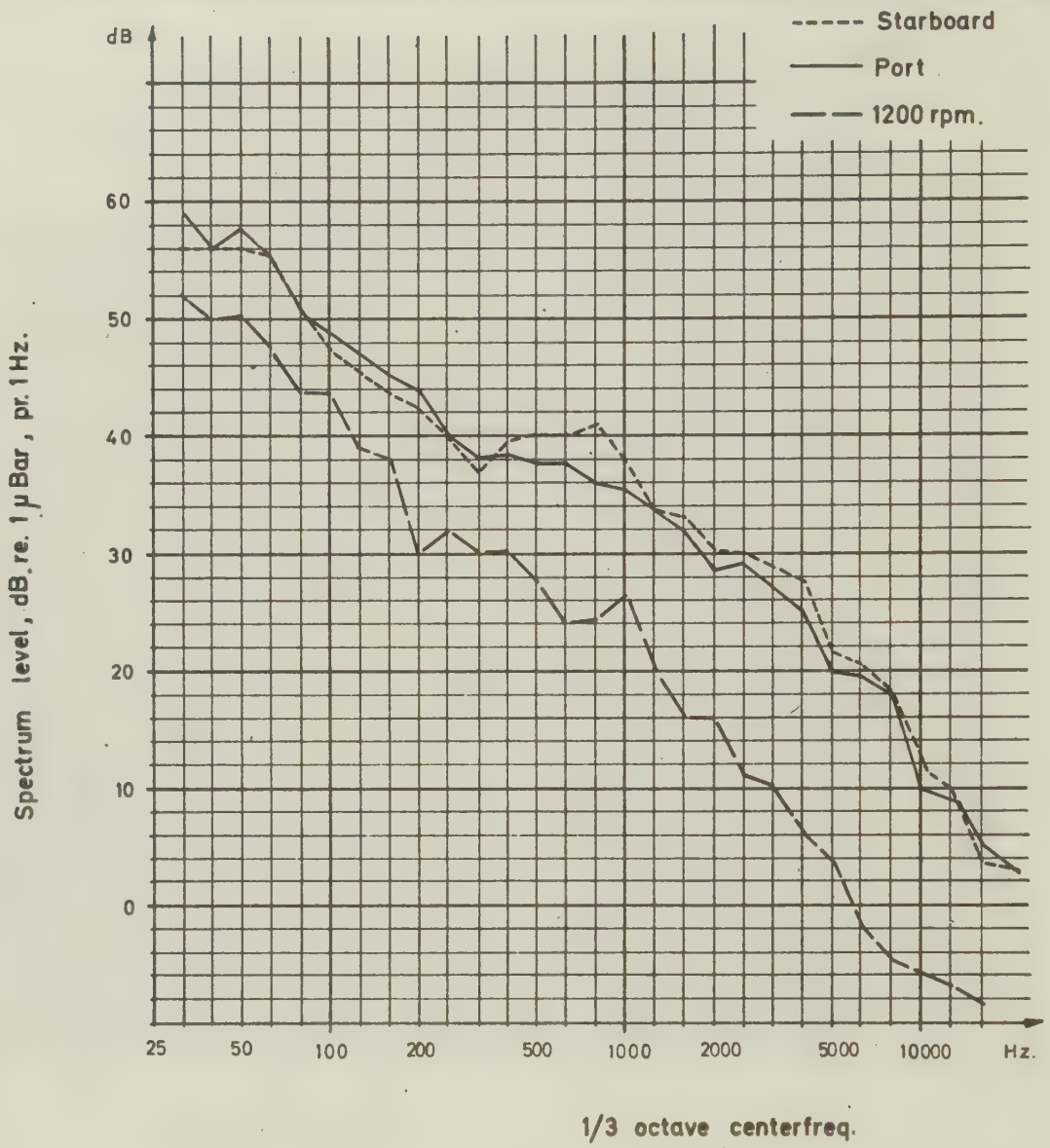

Diagram 7. Observed noise from R/V SNP 1. Main engine working at 1200 rpm, side-propeller working at top speed both ways.

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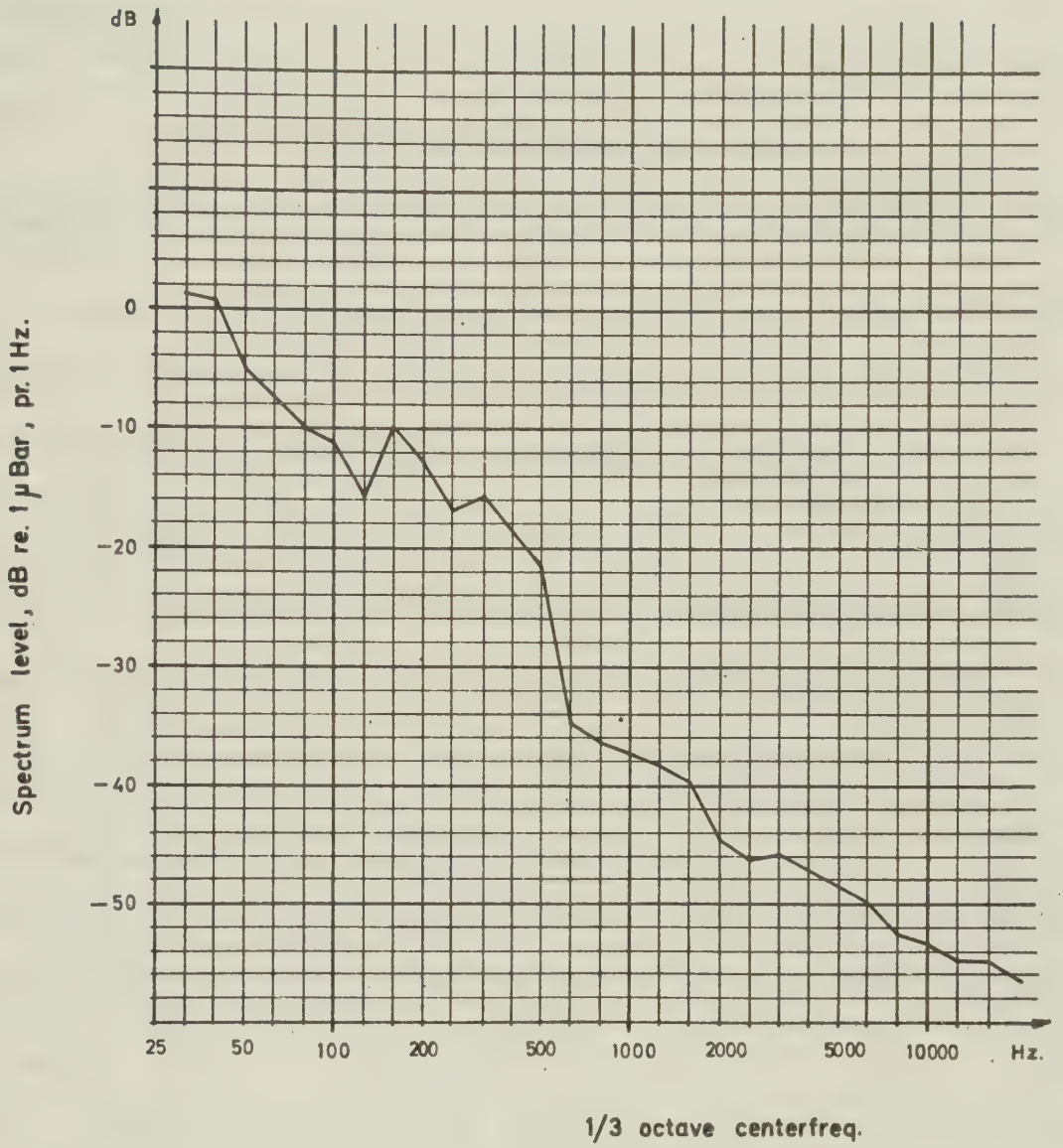

Diagram 8. Observed background noise during noisemeasurements of R/V SNP 1.

SIMRAD SIMONSEN & MUSTAD A.S HORTEN - NORWAY	Wide Band Noise Measurement. Ship : Peruvian R/V "SNP 1."	SUBST. FOR FILE NO.

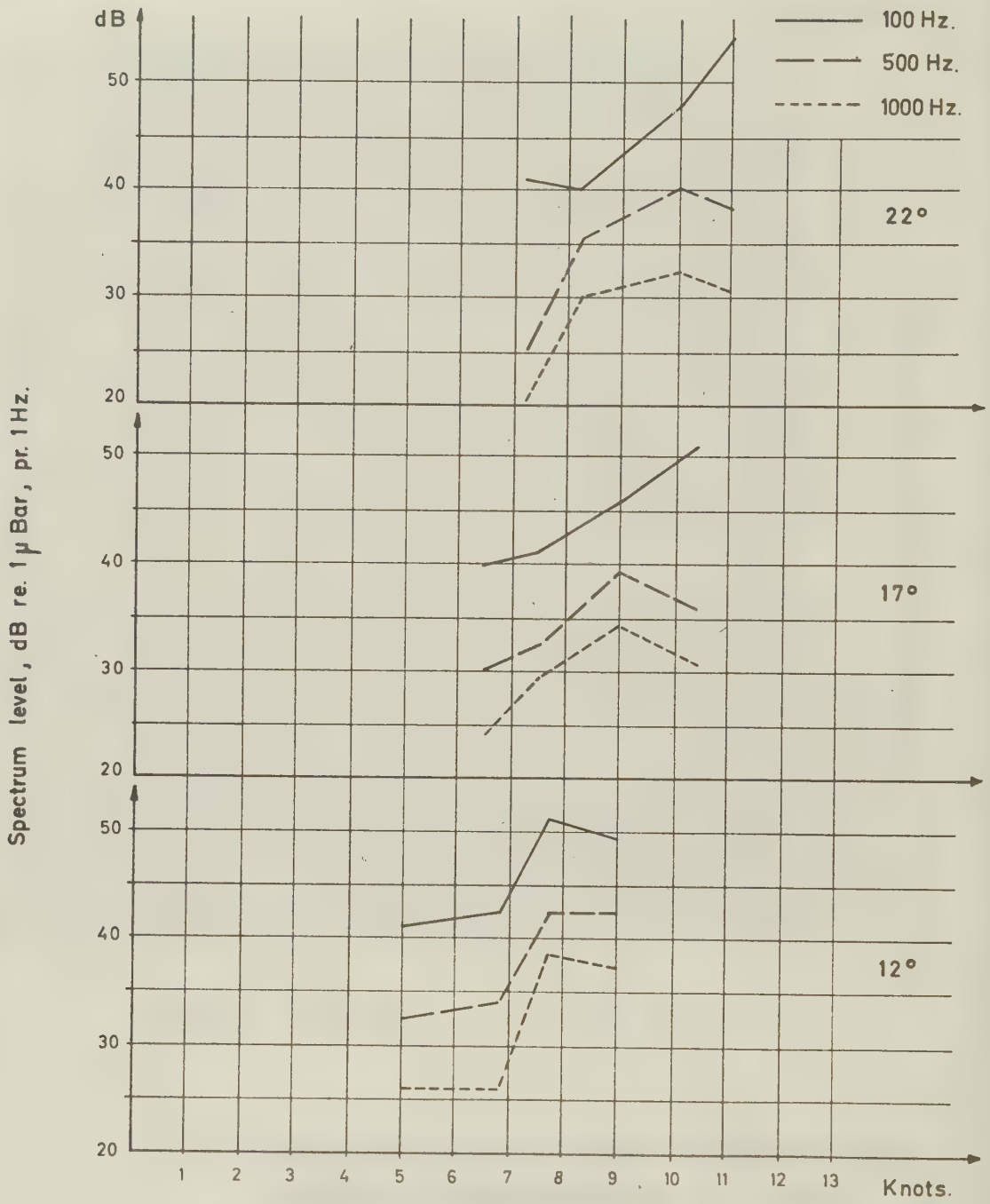

Diagram 9. Observed noise at different speeds measured at centerfrequencies 100, 500 and 1000 Hz.
Pitch: 12, 17, 22°

SIMRAD SIMONSEN & MUSTAD A.S HORTEN - NORWAY	Wide Band Noise Measurement. Ship: Peruvian R/V "SNP 1"	SUBST. FOR FILE NO.

A SELECTED BIBLIOGRAPHY ON UNDERWATER NOISE.

APPENDIX B

(i) Bibliography on the reaction of fish to underwater noise.

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APPENDIX C

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